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Charting the water footprint for Malaysian crude palm oil

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A B S T R A C T

Water scarcity is a serious issue facing our planet right along -side with climate change. The purpose of this study was to evaluate the impacts associated with the use of water by the oil palm trees and the industry for the production of crude palm oil in Malaysia; evaluate the uncertainties of the outcome of a study based on pathway assumptions and the choice of allocation. A full life cycle assessment and a stand-alone water footprint value based on the local water stress index has been determined. The system boundary included the oil palm nursery, plantation (with land use change of oil palm to oil palm and from logged over forest) and palm oil mill (biogas capture scenario). The results showed that the direct water used by the crops and process was minimal because the oil palm plantations in Malaysia were firstly rain fed and not irrigated and secondly Malaysia is located in a region with high availability of renewable water resulting to a low water stress index. The water footprint concluded that the main potential impacts within the system boundary were dominated by land conversion, production and use of fertilisers and pesticides. These findings contradict the general perception of any agriculture system where the notion to assume that the water used by the crop will have the major potential impact. The findings also highlighted the importance of the choice of pathway, government initiatives and managerial intervention for biogas capture which resulted to a 117% reduction in the water footprint. Economic allocation had a 21% increase in the water footprint as compared to weight allocation. It was recommended that plantations implement Good Agricultural Practices that addresses the key elements of land, water management, fertiliser and integrated pest management and the choice of pathways and allocation procedures are made transparent with the results as outcomes may differ as shown in this paper.

1. Introduction

The year 2017 marks 100 years of oil palm cultivation in Malaysia commercially (Zunaira and Hanim, 2017). After 100 years Malaysia is the second largest oil palm producer in the world after Indonesia with an oil palm planted area of over 5.74 M ha (Kushairi, 2017). The oil palm industry has been a strong contributor to the nation's economic growth with annual high export revenues of palm products which was over RM 64.59 G just in the year 2016 (Kushairi, 2017).

Today water scarcity is a serious issue facing our planet right along -side with climate change. Water scarcity arises when the demand for the water exceeds the supply in a certain region (Harhay, 2011). Recognizing the importance of water, focus is now being given to water through water footprint (WF) of products just like carbon footprint. Green-house gas (GHG) emissions are determined using the Life Cycle Assessment (LCA) approach and in the same manner for the quantification of WF the LCA approach has to be used. As defined in WULCA (2014), LCA is a method that is used to evaluate the potential environmental impacts for a product or process over its entire life cycle. WF is a fraction of the whole LCA study. WF accounts for the impacts that are associated with the consumption and discharge of water as well as the availability of water for humans and eco-system (WULCA, 2014).

There have been a large number of studies on WF. Jeswani and Azapagic (2011) reviewed the WF approaches, strengths and limitations reported that there are huge variations in the results

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between different methods. Lovarelli et al. (2016) also conducted a review on WF indicators which highlighted that 78% of the studies aimed to quantify WF, 22% analysed methodology, uncertainty, future trends and comparisons with other footprints and most studies that quantified WF concerned cereals. This shows the high interest of agriculture based industry to quantify their WF. The study in China by Wei et al. (2016) wanted an improved WF model to quantify the WF caused by water diversion. The study also wanted to quantify the crop WF which increased during the transfer. The study concluded that the crops with higher WF_{blue} tend to be more strongly influenced by the water diversion project, due to high water dependency for irrigation. This shows how WF was used to gauge the outcome of a certain projector initiative. Morillo et al. (2015) conducted a joint evaluation of crop WF accounting and irrigation management indicators as a diagnostic tool to identify the hotspots of irrigated agricultural systems. Based on this analysis, specific actions were defined to improve water use efficiency, reduce water abstractions and polluted water returns, while maintaining production rates. In this case WF was used as a tool to identify the hotspots where mitigation actions could be taken to better manage the irrigation system. The study by Pellegrini et al. (2016) which compared WF of different olive agronomic cropping systems found that the high-density cropping systems was found to be most competitive due to the reduced WF. Wong et al. (2016) reported that the differences in water use between feed stocks and conversion process indicated that the choices of biomass feedstock and conversion pathways were crucial factors affecting the WF for the study which quantified the WF of hydrogenation-derived renewable energy. Sabli et al. (2017) created a method in calculating WF found the method can only provide water degradation levels in the plantations. Xu et al. (2015) estimated the total water consumption of crop production in Beijing and found that crop production shows a greater blue WF than green and grey. Chiu et al. (2015) calculated the WF of 2nd generation bioethanol. Dourte et al. (2014) reported the development of a web based tool which provides a local water stress index (WSI) based on regional water use and available supplies. This showed how WSI is an important indicator in WF as well. Lovarelli et al. (2016b) created a pollution water indicator to denote the water pollution intensity. This was mainly to identify the effect of the main polluting substances in crop cultivation. This study again shows how important WF studies are in agricultural based systems. Duarte et al. (2014) examined the evolution of domestic water consumption in Spain due to the increase of agricultural production and found that pressures on water resources exerted as a result of the expansion of the Spanish agricultural sector. Mekonnen and Hoekstra (2014) established a set of global WF bench mark values for a large number of crops grown in the world. There was also a study charting the WF of all the various vegetable oils and crops (Gerbens et al., 2008). A study in Malaysia quantified the WF of crude palm oil (CPO) (Subramaniam et al., 2014) and recently a study in Thailand quantified the blue, green and grey WF of CPO (Suttayakul et al., 2016). The findings of both these studies showed that the highest impact was from of the water used by the oil palm trees which was the green water. Both these studies reported the quantity of the water used by the crop without considering the impact of the water used based on the availability of water in the region. This paper aims to study the impact of the consumption of water by the crop based on the availability of the water in the region.

There has been a lot of debate on the applicability and uncertainties regarding WF but these studies show that WF can bring about important managerial decisions and mitigation steps that can be derived for better utilisation of water. At the same time outcome of improvements and modifications to any system can be gauged with the WF as well.

This study is a National WF study having representative data from 243 palm oil mills (POMs) from all over Malaysia. This study also accesses the impact of the quantity of water needed by this industry to determine the hotspots where water is used along the supply chain and if the potential impact of the water used is coming from the crop water use (which is the general perception of any agricultural system) or if it is from other sources. This study also addresses the uncertainties of the outcome of a study based on pathway assumption (in this case when the biogas capture scenario was chosen) and choice of allocation.

The main motivations or problems statements of this study are as below:

1. An average oil palm plantation is planted with 136–148 oil palm trees per ha (Hashim et al., 2010). With a large land cover of over 5.74 M ha this accounts to having 780.64 M - 849.52 M oil palm trees standing in various ages in the country. The water requirement of these oil palm trees and the identification of areas that are suitable for planting are very crucial. The findings of this study was hoped to enable better decision making on areas that are suitable for planting oil palm trees as well as for the formulation of better water managerial practices at the plantation. The findings of this study can also inform the policy makers and the stakeholders of the hotspots of where the potential impact on water consumption exits along the supply chain of the system boundary.
2. The European Commission launched their pilot study on environmental footprint between 2013 and 2016 (European Commission, 2016). The Environmental footprint takes out the impact categories of global warming and air pollution (GHG emissions) and water pollution or scarcity (WF) from the full LCA for reporting purposes. The European Union being the second largest importer of Malaysian palm oil with a total export of 2.03 M t of CPO in the year 2016 (Kushairi, 2017) may require such accounting for their imports in the future and so WF conducted in accordance to ISO 14046:2014: Environmental Management WF- Principles, requirements and guidelines (ISO/TC207, 2014) is important for the Malaysian oil palm industry.
3. The Government of Malaysia has launched the National Key Economic Area (NKEA) where all POMs will have to capture the biogas (Pemandu, 2011). The adoption of this endeavor has only recently picked up. This study hopes to quantify the magnitude of this Government intervention towards the WF of the industry. Even though the GHG emissions have been gauged before but the WF has never been gauged. This study also aims to evaluate the importance of such interventions by the government to make a revolutionary change in an industry by doing a sensitivity analysis if the NKEA was never launched and to highlight how a pathway choice in a study can reduce the impacts drastically.
4. Allocation based on weight, energy or economics is a common step used in LCA. This WF study aims to show how an outcome of a study can change with just an allocation decision.

The purpose of this study was to

- Evaluate the impacts associated with the use of water by the oil palm trees and the oil palm industry and suggest mitigation measures if any
- Evaluate the uncertainties of the outcome of a study based on pathway assumptions (in this case when the biogas capture scenario was chosen)
- Evaluate the uncertainties of the outcome of a study based on the type of allocation decision.

2. Materials and method

There are many WF methods available to conduct the assessment. The fact remains that there are huge variations in the WF findings between different methods (Jeswani and Hoekstra, 2011). What is important is that the method uses the life cycle approach and conducts an impact assessment. The method chosen for this study is in line with the ISO 14046:2014: Environmental Management WF- Principles, requirements and guidelines (ISO/TC207, 2014) and is also a method that is listed in the WULCA working group (WULCA, 2014).

WULCA was formed to focus on the initiatives of WF in the life cycle perspective. This international working group develops and compiles methods that are in line with the life cycle perspective for all matters relating to water use (WULCA, 2014).

A full LCA was carried out to determine the potential impacts using the ReCiPe LCA method with the SimaPro version 8.0.4. The end-point ReCiPe was used. ReCiPe is one of the harmonized indicator approaches available in life cycle impact assessment (LCIA) (Goedkoop et al., 2009). The full LCIA will present the potential impacts for the WF. The (Ridoutt and Pfister, 2013) method was conducted to obtain a stand-alone number for the WF that was calculated based on the local WSI. This method gives a much localized impact assessment as water ways differ from region to region.

One of the most commonly used measures of water scarcity is the 'Falkenmark indicator' or WSI. WSI: 0 (no stress) − 1 (extreme stress). This measure defines water scarcity in terms of the total availability of water to the population of a region; measuring scarcity as the amount of renewable freshwater that is available for each person each year (UNESCO, 2012). If the amount of renewable water available in a country per person is less than 1700 m^3 per year, that country is said to be experiencing water stress (UNESCO, 2012).

According to the method the WF is calculated as a total of the consumptive water use (CWU) which relates to the removal of water from a water body, and degradative water use (DWU), which relates to the emissions that influences the water quality (Ridoutt and Pfister, 2013). The WF is expressed in the unit of H_2Oe where 1 L H_2Oe represents the burden on water systems from 1 L consumptive freshwater use at the global average WSI.

The formulas are as in the box.

- $\mathrm{WR} = \mathrm{CWU}(\mathrm{H_2Oe}) + \mathrm{DWU}(\mathrm{H_2Oe})$ ——————————————— (1)
- $\mathrm{CWU}(\mathrm{H_2Oe}) = \sum_i \frac{\mathrm{CWU_i} \times \mathrm{WSI_{local}}}{\mathrm{WSI_{glocal}}}$ ———————————————(2)
- $\mathrm{DWU}(\mathrm{H_2Oe}) = \frac{\text{ReCiPe points(emissions to water for product system)}}{\text{ReCiPe points(global average for 1 L consumptive water use)}}$ —————— (3)

(Ridoutt and Pfister, 2013)

The CWU calculations are based on the WSI of a country. The WSI of Malaysia is taken as 0.05 as a mid-point of WSI of Malaysia which is below 0.1. The global WSI as stated in (Ridoutt and Pfister, 2013) is 0.602.

In order to calculate the DWU, the weighted results from the full LCIA was used. The impact categories included were climate change human health, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, ionising radiation, freshwater eutrophication, freshwater ecotoxicity and marine ecotoxicity. According to Ridoutt and Pfister (2013) the global average value for 1 L of CWU was assessed and found to be 1.86×10^{-6} ReCiPe points.

The WF accounts for both the direct and indirect water used in the system boundary. The direct water is the water that is applied directly into the system for irrigation or application of fertilisers, pesticides or into the processing system as water. The indirect water is the water that is used to produce materials used in the system boundary. The product like diesel or fertiliser or pesticides etc is used within this system boundary but the production of these products were not carried out at the system boundary. The data of these indirect water was obtained from the Eco-invent database in the Simapro Software when the LCIA was carried (which are the background data) and was accounted for in the LCIA and the DWU calculations as well. All forms of water used in all the inputs and outputs of the system boundary are accounted for.

2.1. System boundary

The system boundary starts at the nursery stage where the germinated seeds are planted in poly bags. The oil palm seedlings are irrigated with sprinklers. Herbicides and fertilisers are also applied. After 10–12 months these healthy seedlings will be transplanted in the oil palm plantations to become oil palm trees. The oil palm plantations in this study are rain fed and do not have any sort of irrigation in place which is the case for the majority of the oil palm plantations in Malaysia. The only water input is during the pesticides application. When the oil palm trees are three years old, they start to bear fruits which are called oil palm fresh fruit bunch (FFB). The FFBs which are harvested when ripe are transported to the third stage of the supply chain which is the POM. The FFBs have to be transported within 24 h of harvesting and cannot be stored as this affects the oil quality. The economic life cycle of an oil palm tree is 25 years after which they are cut down to be replanted with new oil palm seedlings. Two land use change (LUC) scenarios were examined at the plantations which were the continued LUC of oil palm to oil palm which means that the previous land use was oil palm and the LUC from logged over forest (LOF). The data for the LOF LUC was obtained from (Lasco, 2002) while the oil palm to oil palm was obtained from (Syahrinudin, 2005).

In Peninsular Malaysia almost all the oil palm plantations have the continued LUC scenario because oil palm plantations here are in their second or third cycle of replanting as one life cycle of the oil palm tree is 25 years. In Sabah and Sarawak the allotted agriculture land for new plantations are from LOF. This study does not cover oil palm plantations on peat soil and only covers oil palm plantations on mineral soils.

At the POM the FFBs are processed into CPO after going through the milling process which involves sterilisation, stripping of the fruitlets from the FFB, digestion and mechanical pressing to extract the CPO. The water for the process is mainly for steam production to run the turbine to generate electricity for the POM as well as for the sterilisation process to cook the FFB. Water is also directly used for dilution in some POMs and for washing. Previous LCA studies like (Choo et al., 2011) carried out two different scenarios at the POM. The same with (Subramaniam et al., 2010) where there is a biogas emission and biogas capture scenario. At the POM the biogas is emitted from the anaerobic treatment of the palm oil mill effluent (POME) which is the waste water of the milling process. However for this study the biogas capture scenario was chosen because under the Economic Transformation Programme (ETP) which was launched by the Government of Malaysia in 2011, palm oil was identified as one of the NKEA. Under this NKEA entry point project 5 (EPP5) envisages that all POMs in Malaysia will have a biogas capture facility (Pemandu, 2011). In 2016 about 20% of the POMs in Malaysia have bio-digesters to treat and trap the biogas while another 35% of the POMs were in the various stages of implementing; planning and constructing these biogas capture facilities. There were also other POMs that are implementing methane avoidance measures to avoid the formation of biogas. In view of this the calculations for the WF will be for the biogas capture scenario.

The production of CPO has two by-products (Fig. 1) which are the palm kernel (PK) and palm shell (PS). The FFB contains oil palm fruitlets which consist of the outer layer mesocarp which surrounds the nut. The CPO is pressed from the mesocarp while the nut contains the PK and when cracked it produces the PK and PS. About 10% of the PSs are used in the biomass boiler in the POM to be burnt with all the pressed mesocarp fibre to generate heat which is used to produce steam to run a turbine that generates electricity for the whole milling process. The excess PSs are sold to other biomass boiler users while the PKs are transported to the kernel crushing plants to be processed into crude palm kernel oil. Weight allocation was carried out between CPO, PK and PS which were 58%, 24% and 18% respectively.

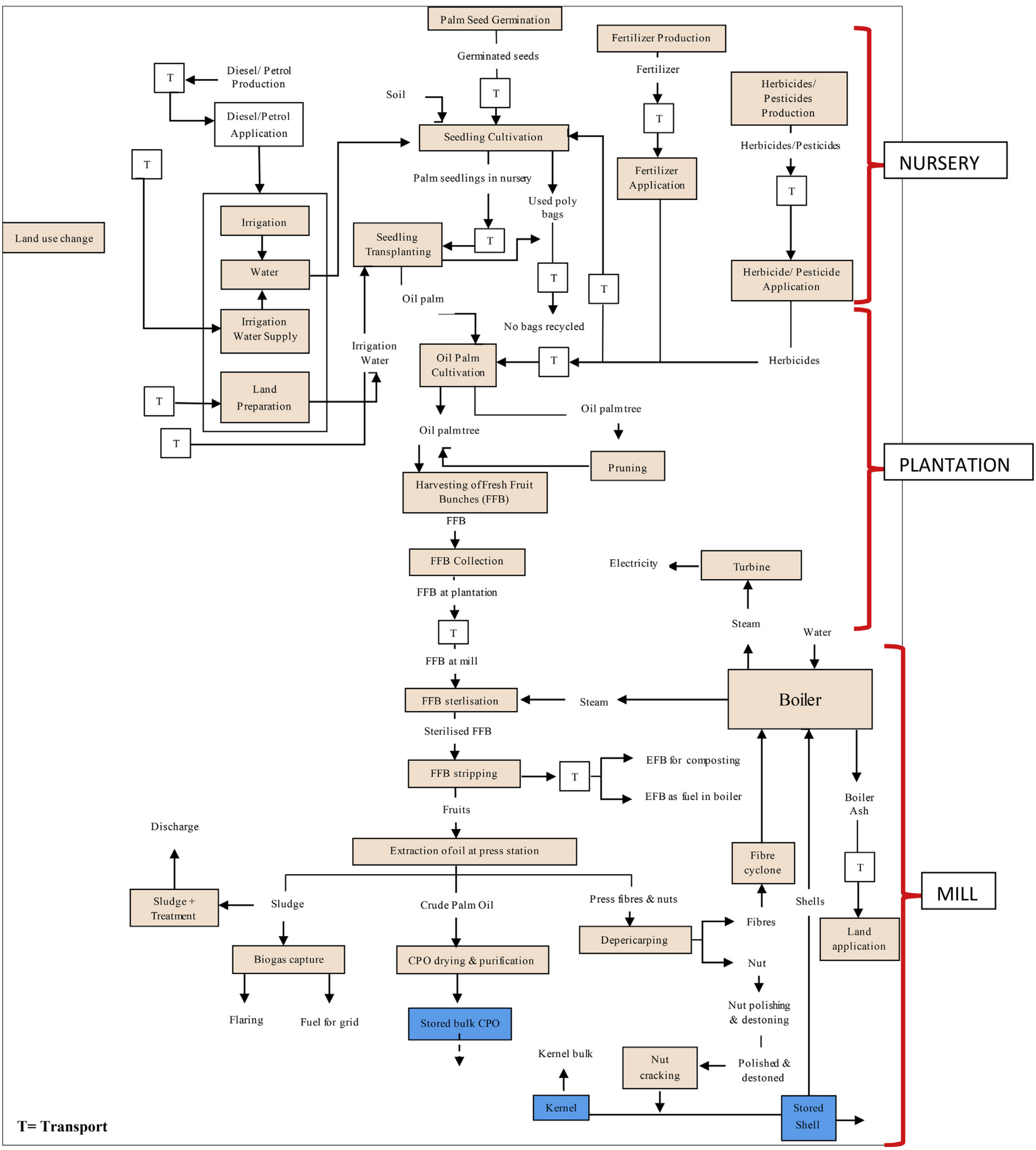

Fig. 1. System boundary.

Table 1
LCI for the production of oil palm seedling per t CPO (Muhamad et al., 2014).

Input	per t CPO
Electricity Grid (kWh)	9.9E-03
Diesel (L)	6.60E-03
Polybag (kg)	3.46E-03
Water (direct) (L)	800.00
N (kg)	8.41E-04
P_2O_5 (kg)	4.29E-04
K_2O (kg)	3.47E-04
Thiocarbamate (kg)	1.85E-05
Pyrethroid (kg)	5.84E-06
Organophosphate (kg)	3.3E-05
Dithiocarbamate (kg)	1.58E-04
Unspecified Pesticide (kg)	2.22E-06
Urea/sulfonylurea (kg)	3.58E-05
Glyphosate (kg)	1.46E-05
Van (<3.5 t) (tkm)	1.06E-08

Table 2
The characteristics of the plantations used in the study (Hashim et al., 2010).

Plantation characteristics	
Fresh Fruit Bunch yield (t/ha/y)	20.70
Planting density (palm/ha)	142.00
Soil characteristics	Mineral soils
Plantation lifetime	25 y
Number of plantations	102.00
Total area	1.10 M ha (93.7% mature and 6.3% immature)

3. Results and discussion

3.1. Life cycle inventory

The LCI data for the nursery covered 21 oil palm nurseries in Malaysia (Table 1).

The direct water consumption at the nursery originated from the water consumption from the sprinklers for irrigation which amounted to 0.16 m^3/tFFB (Muhamad et al., 2014). The other source of direct water at the nursery was from the application of pesticides which amounts to 0.00002 m^3/tFFB. The indirect water consumption comes from the production and application of fertilisers and pesticides; as well as for the production and use of polybags; diesel in pumps and transportation.

The next stage is the plantation (Table 2) where the oil palm seedlings are transplanted to the plantation. The LCI data for the oil palm plantations covered 281 oil palm plantations (Table 3).

Unlike the nursery stage, there was no irrigation conducted at the plantation stage. The direct water only comes from the application of the pesticides which amounts to 3.56 m^3/t FFB (Hashim et al., 2014).

The harvested FFBs at the plantation are transported to the POMs where they are processed into CPO. The LCI data was collected from 243 POMs. The average LCI data for the POMs are shown in (Table 4).

The source of the direct water consumption at the POMs was for the boiler and for processing and cleaning purposes which amounts to 5.5 m^3/tCPO. The direct water used for the various stages in the system boundary is as shown in (Fig. 2*)*. The total direct water consumption for CPO production from nursery till the POM was 24.10 m^3.

3.2. Life cycle impact assessment

The weighted LCIA of the production of CPO for LOF to oil palm and oil palm to oil palm LUC are as shown in (Figs. 3 and 4) respectively.

Table 3
LCI for the production of FFB per t CPO (Hashim et al., 2010).

Input	per t CPO
Diesel for agriculture machinery (L)	11.85
Oil palm seedling (transplanted)	1.65
Water (direct) (L)	17,800.00
Ammonium sulphate (kg)	40.25
Urea (kg)	2.05
Ammonium nitrate (kg)	3.80
Ammonium chloride (kg)	3.60
N from compound, mixture (kg)	5.80
N from fertilizer application (kg)	17.45
Muriate of potash (kg)	58.00
K_2O from compound, mixture (kg)	22.50
K_2O applied (kg)	57.50
Phosphate rock (kg)	32.75
P_2O_5 from compound, mixture (kg)	3.20
P_2O_5 (kg)	14.00
Glyphosate (kg a.i)	1.69
[Sulfonyl]urea compounds (kg a.i)	0.74
Bypyridylium compounds (kg a.i)	0.52
Pyretroid compounds (kg a.i)	0.11
Organophosphorus compounds (kg a.i)	0.32
Carbofuran (kg a.i)	0.18
2,4-D,dimethylamine salt (kg a.i)	0.16
Pesticide unspecified (kg a.i)	10.44
Transportation of FFB to mill (tkm)	250.00
Transportation of fertilizer from port (tkm)	25.50
Transportation of pesticides from port (tkm)	0.75

Table 4
LCI data for the production of 1 t CPO from 243 POMs in Malaysia.

Parameter	1 t CPO	Range
Fresh Fruit Bunch (t)	5.10	4.80–5.30
Electricity Grid (MJ)	4.00	0.00–9.00
Renewable electricity turbine (MJ)	377.00	363.00–400.70
Diesel used in POM (MJ)	216.00	160.00–273.00
Transport of Diesel to POM (tkm)	1.00	0.80–1.20
Palm Kernel (t)	0.42	0.39–0.44
POME (m^3)	3.30	3.00–3.60
Water (direct) (m^3)	5.50	3.50–7.50
Empty Fruit Bunch (t)	1.17	1.09–1.22
Excess PS (t)	0.32	0.30–0.33

The main potential impacts for the LOF to OP LUC were caused at the plantation phase under the climate change human health impact category which was due to the land conversion as well as the production and application of fertilisers and pesticides. At the POM the emissions from the residual biogas from POME which was assumed at 90% capture efficiency also minimally contributed towards this category. The next potential impact was for the fossil fuel depletion impact category which was again caused by the plantation phase due to the production and transportation of the fertilisers and pesticides. For the oil palm to oil palm LUC scenario (Fig. 4) the intensity of the climate change human health impact category reduces due to the elimination of the transformation of the land.

3.3. Water footprint

The WF which is the sum of $CWU(H_2Oe) + DWU(H_2Oe)$ (1)
The CWU calculations are as below:

$CWU(H_2Oe) = (24.10\ m^{3}*0.05)/0.602 = 2.00\ m^3\ H_2Oe/tCPO.$ ——————————(2)

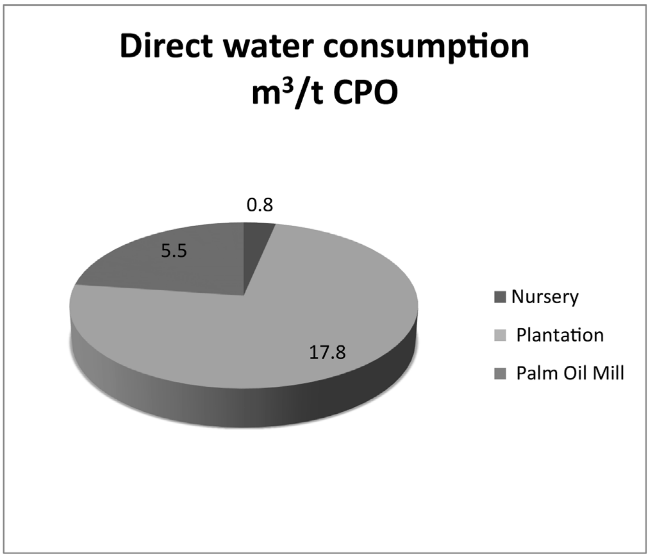

Fig. 2. Direct water consumption at the various stages (m^3/t CPO).

For the DWU, the first scenario was the continued LUC from oil palm to oil palm at the plantation with biogas capture at the POMs (Table 5).

DWU $(H_2Oe)_{OP\ to\ OP}$= $(38.85/1.86 \times 10^{-6})/1000\ m^3 = 20885\ m^3$ H_2Oe/tCPO. ——————————————(3)

The second scenario was the LOF LUC at the plantation with biogas capture at the POMs (Table 6).

DWU $(H_2Oe)_{LOF\ to\ OP} = (46.75/\ 1.86 \times 10^{-6} =)/\ 1000m^3 = 25132\ m^3$ H_2Oe/tCPO. ——————————————(3)

The WF for 1t CPO produced for the two scenarios are shown in (Fig. 5).

The WF of the LUC from the LOF was about 20% larger than the continued LUC scenario which is basically due to the land conversion from logged over forest. The surprising finding was that the most significant impacts came from the DWU which was the indirect water use for the production and use of energy, fertilisers, pesticides and POME treatment which contributed towards the WF.

The general perception in any agriculture based product would be the concerns about the water used directly by the crop which was one of the objectives for this study to gauge the impact of the water used by the oil palm trees. The results showed that the direct water use by the crops and process was minimal. This is because the oil palm plantations in Malaysia are firstly rain fed and not irrigated and secondly Malaysia is located in a water abundant region with very high availability of renewable water and a very low WSI. Malaysia is located near the equator making it hot and humid all year long. The average temperature is 27 °C and has an average

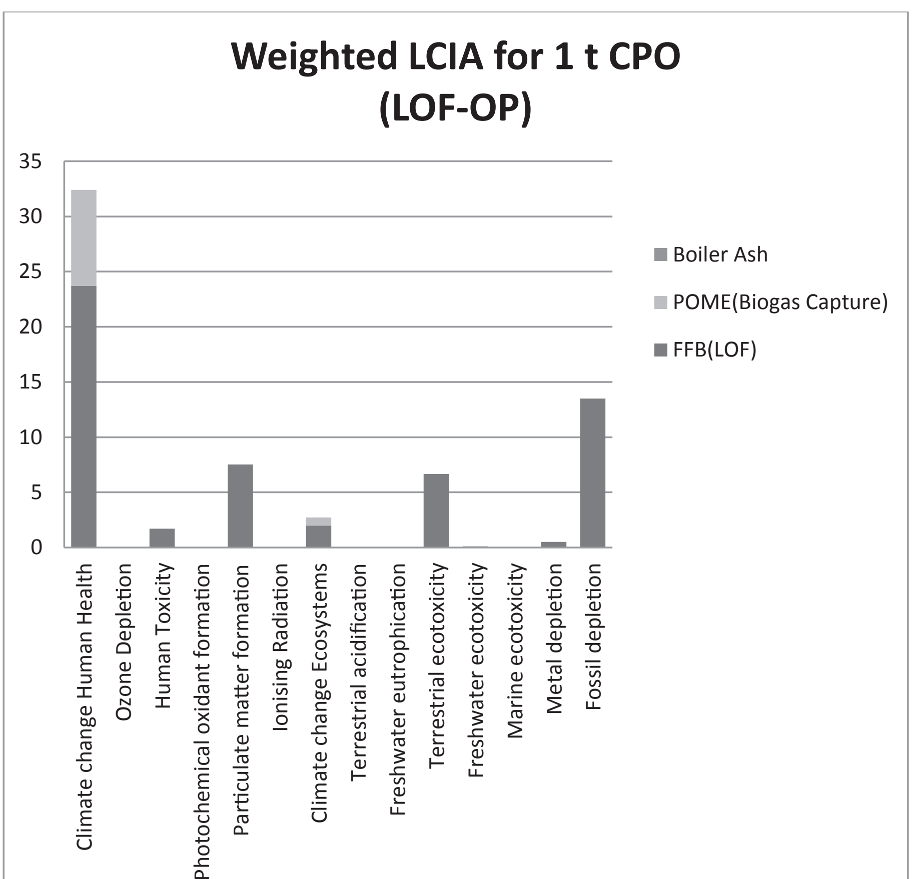

Fig. 3. Weighted LCIA for 1 t CPO for LUC from LOF to oil palm.

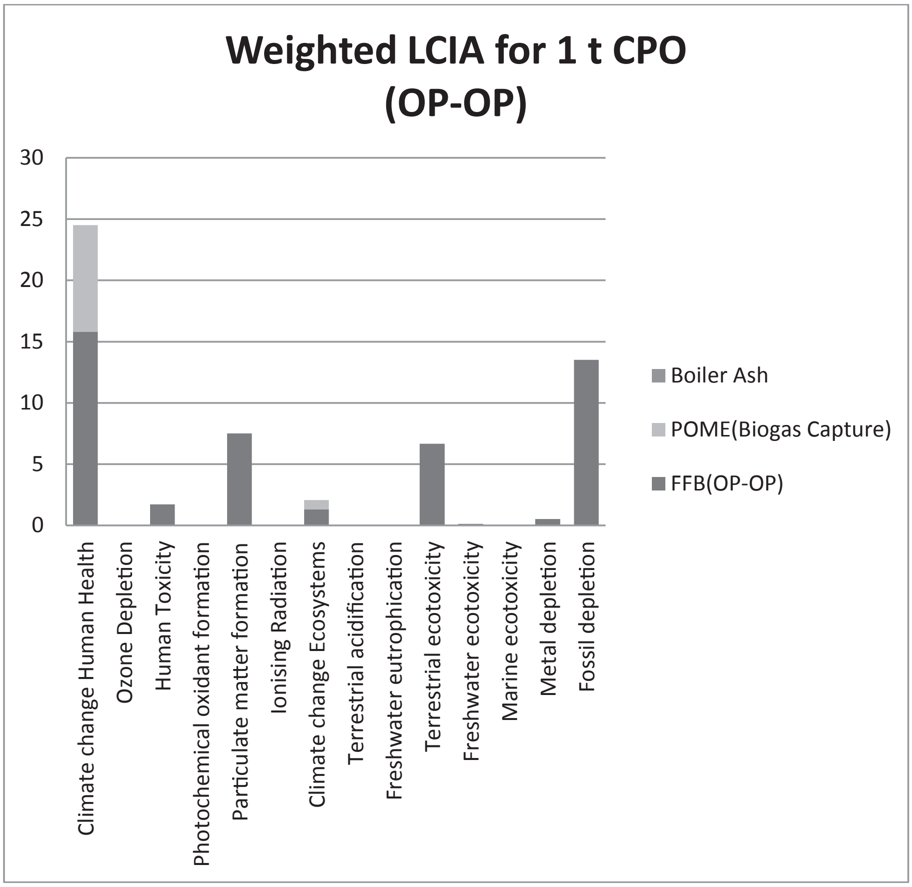

Fig. 4. Weighted LCIA for 1 t CPO for LUC from oil palm to oil palm.

Table 5
Weighted points for LUC from oil palm to oil palm for 1 t CPO.

Impact categories	Weighted points (Pt)
climate change human health	28.1
ozone depletion	0.00349
human toxicity	1.75
photochemical oxidant formation	0.00336
particulate matter formation	8.84
ionising radiation	0.00531
freshwater eutrophication	0.0259
freshwater ecotoxicity	0.117
marine ecotoxicity	0.00144
Total	38.85

Table 6
Weighted points for LUC from LOF to oil palm for 1 t CPO.

Impact categories	Weighted points (Pt)
climate change human health	36
ozone depletion	0.00349
human toxicity	1.75
photochemical oxidant formation	0.00336
particulate matter formation	8.84
ionising radiation	0.00531
freshwater eutrophication	0.0259
freshwater ecotoxicity	0.117
marine ecotoxicity	0.00144
Total	46.75

rainfall of over 2500 mm/y (Nur Amira, 2015) resulting Malaysia to have a WSI that is less than 0.1 (Pfister et al., 2009). According to the UN World Water Development Report (United Nations, 2015) on the access to renewable water sources, the Malaysian region has 15,000 m^3 to 50,000 m^3 water/person. This puts Malaysia way above the range in the WSI definition where the minimum requirement is 1700 m^3/person.

This is important because consumption of water in a region with high availability of water will not have the same implications or impacts as water consumed in regions that are scarce in water availability (Ridoutt and Poulton, 2009). The other reason was also due to the high yields per hectare for oil palm trees of 21 t FFB/ha/y.

The DWU or indirect water is largely contributed by the climate change impact category and particulate matter formation. Both these impact categories are linked with gaseous emissions. The main gaseous emission in this system boundary comes from the application of fertilisers and pesticides in the nursery and field. The fertiliser requirements of oil palm depend on many interrelated factors that vary from one environment to another (Goh et al., 2010).

Proper fertilisation is the most important contributor for yield. Fertilisers not only have the greatest impact on productivity but also commonly constitute the highest operational cost in well run plantations in Malaysia. It plays a pivotal role in the profitability of oil palm. This is one of the reasons the main potential impacts are coming from the production and application of fertilisers. This impact has to be addressed and will be discussed in detail at the end of this section.

As described in section 2, weight allocation was performed with the by-products and the WF is as shown in (Fig. 6).

When weight allocation was performed the WF values reduced by 42% for both LUC scenarios as the burdens are shared with the

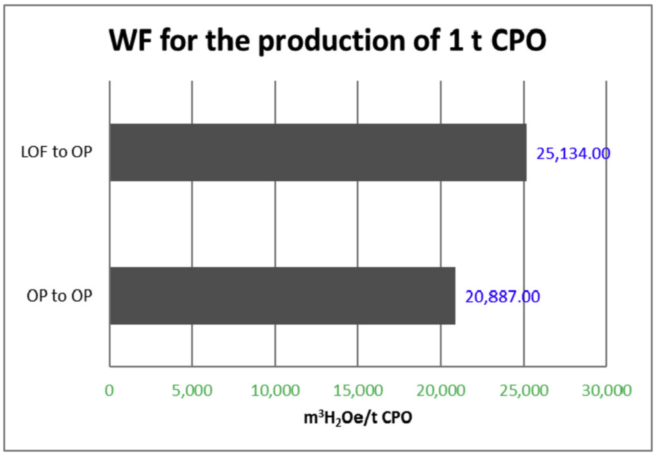

Fig. 5. WF for the production of 1 t CPO.

other two by-products. In most LCA studies allocation is often carried out as very rarely a system will only yield one product without any by-products. Not much attention is given to the decision on the kind of allocation if weight or economic is carried out as it is assumed that the outcome from the various different allocations between the by-products will give similar findings. In order to check if allocation procedures give the same outcome, a sensitivity analysis has to be carried out for every study that carries out allocation. The sensitivity analysis for this study is reported in section 4.4 in this paper.

The WF concludes that the main potential causes of the impacts within the system boundary was mostly dominated by the land conversion, production and use of the fertilisers and pesticides. These finding may contradict the general perspective of any agriculture system where the notion to assume that the water used by the crop will have the major potential impact. In order to check the validity of these findings a sensitivity check was conducted with a different methodology as reported in section 4.2.

To reduce the impacts which are dominated in the oil palm plantation, the management of the whole plantation is very important. The plantation has to implement Good Agricultural Practices (GAP). Over the past two decades, conventional agriculture exemplified by the Green Revolution, has given way to sustainable agriculture. A sustainable agriculture system is a system that produces the crop without affecting the environment as well as the surrounding ecosystem. There are a few issues which are connected to agriculture like fertiliser usage, the availability of resources like sunlight, water and wind. While all these factors are equally important for the growth of the crop, fertilisers are given extra importance, as they are the ones that help plants in the initial stages of growth. Fertilisers are materials of synthetic or natural origin which are applied for supplying plant nutrients crucial for growth. Fertilisers are meant for enhancing growth (Bulagric, 2016).

The Third National Agricultural Policy, 1998–2010 provided the basis for initiatives in sustainable agriculture. As climate change becomes an increasingly important issue, sustainable agriculture can contribute to both climate mitigation and adaptation. GAP ensures the sustainability of its plantation operations. The key elements of GAP are land, water management, fertiliser management, and integrated pest management (IPM) (Tradewinds, 2017a). More details on the key elements of GAP will be discussed in section 5.0 under recommendations.

4. Sensitivity analysis

A sensitivity check ensures the reliability of the final results and conclusions by determining how they are affected by factors such as data uncertainties, allocation methods or assumptions. Four sensitivity analysis were carried out for this assessment.

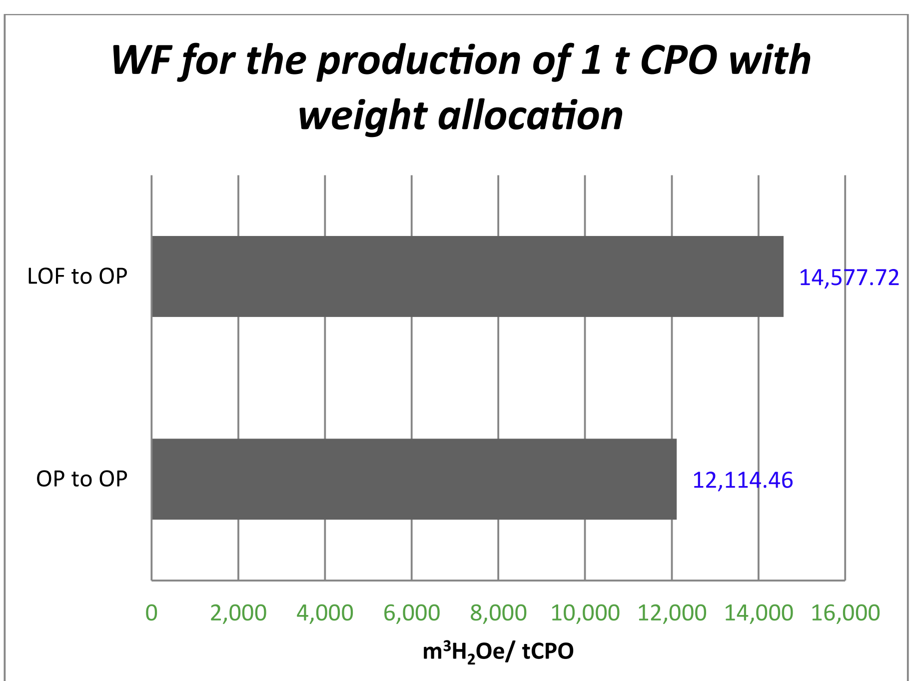

Fig. 6. WF for the production of 1 t CPO with weight allocation.

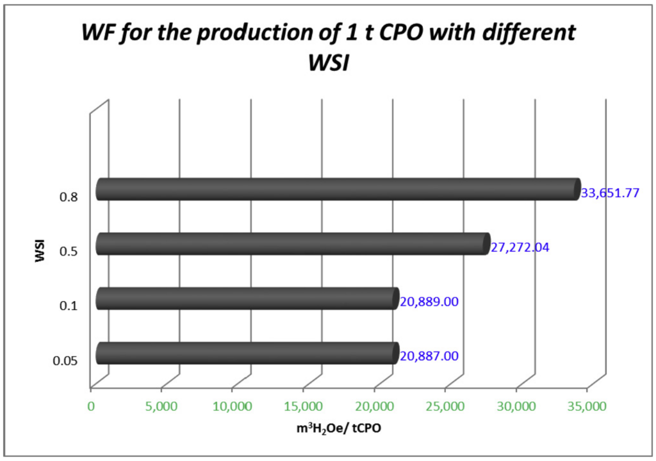

Fig. 7. WF for the production of 1 t CPO with different WSI.

4.1. Different WSI values

First was to check the different value of WSI. Comparison was made to examine the difference in the WF value at different WSI values. If a region is said to be experiencing water stress the availability of water in the soil moisture will be very low leading towards the need for irrigation as well. So the water input will have to be increased with irrigation. This increases the direct water input.

At the WSI exceeding 0.2 irrigation has to be carried out. According to Roslan and Haniff (2004) under normal climatic conditions, the annual potential evapotranspiration of mature palms was about 5.5–6.0 mm/d. During drought, which is considered an occurrence of a substantial water deficit, the evapotranspiration was 7–8 mm/d. Severe drought caused the evapotranspiration to reach as high as 10 mm/d. So for regions with high WSI the higher ET rates were used to do this sensitivity study.

WSI 0.5; ET rate = 8 mm/d and WSI 0.8; ET rate = 10 mm/d.

The direct water used (including irrigation is calculated as the water needed by the crop) for 1 t CPO with the same yield.

Total direct water at:

WSI 0.5 = 7690 m3/ t CPO and WSI 0.8 = 9,707m3 /t CPO.

CWU(H2Oe)WSI 0.5 = (7690 m3*0.5)/0.602 = 6,387.04 m3 H2Oe/ tCPO.

CWU(H2Oe)WSI 0.8 = (9607 m3*0.8)/0.602 = 12,766.77 m3 H2Oe/ tCPO.

The WF for 1 t CPO with different WSI for the oil palm to oil palm LUC is shown in (Fig. 7).

This findings show that WSI directly correlates with the need for direct water input in the crops. The WF increase from WSI 0.05 and 0.1 is not very significant but WSI 0.5 and WSI 0.8 incurred a WF increase of 31% and 61% respectively as compared to the original levels. This shows the high influence of the WSI levels on the final WF and also how important it is to base the water used in any system against the WSI of the region to gauge the impact of a product based on the water availability of the region.

4.2. Different method

The second sensitivity analysis was carried out to compare the findings when carried out with another method. This was carried out for the oil palm to oil palm LUC. The method chosen for comparison was the Ecological Scarcity 2013. The LCIA was carried out with the SimaPro software version 8.0.4. The results are shown in (Fig. 8).

The weighted results show similar results of the ReCiPe method which was used for the WF calculations where the main potential impact comes from the application of fertiliser and pesticides from the plantation which is from the indirect water used. The potential impacts from the direct use of water in the system should show significant potential impacts under the impact categories water resources, water pollutant and persistent organic pollutants (POP) and heavy metals into water. The analysis shows that even with a different method the potential impacts are still dominated by the production and application of fertiliser and pesticides which contribute towards the indirect water used.

4.3. Comparison on different pathways

The third sensitivity analysis was performed on the biogas option at the POMs. Comparison was carried out to evaluate the difference if there was no biogas capture at the POMs. The difference in the WF values are as shown in (Fig. 9).

This comparison maybe has an obvious outcome but this was an important sensitivity analysis to be carried out to gauge the magnitude of the biogas emissions. This was also carried out to show how a government initiative and managerial policies within the company can drastically change the outcome of the WF values.

The results showed a very significant difference in the WF values between the biogas capture and biogas emissions scenario. There was a 117% increase in the WF if biogas was not captured. This was an important figure to show the savings this initiative can bring about which required millions of ringgit in investments by the industry. This also showed on how an assumption on the pathway can drastically alter the findings of a study where in this case the pathway was chosen based on the government initiative to make all the palm oil mills capture their biogas. The findings also highlight how the impact is reduced by this government intervention and the importance of interventions by the authorities or government to push the industry to reduce their impacts.

4.4. Type of allocation

The fourth sensitivity analysis was carried out on the type of allocation that was used. Comparison was carried out to examine the difference when economic allocation was carried out with the by-products. The price of CPO and PK fluctuates and for this evaluation the average prices for the first half of the year 2016 was used (EIDD MPOB, 2016). The difference in the WF values are as shown in (Fig. 10).

The results show a 21% increase in the WF of CPO with economic allocation. This is because even though the price of PK is slightly lower but the price of PS is extremely low resulting to a larger share being transferred back to CPO as compared to when weight allocation was carried out.

In this manner an allocation decision can increase or decrease the impacts, in this case the WF of CPO. It is very common to carry out allocation in LCA studies and when the final findings are presented, the allocation type is often not focused on and it is only presented in the sensitivity analysis. The ideal situation would be to avoid allocation and conduct a system boundary expansion. This is mostly not possible due to the availability of data, time and cost constrains.

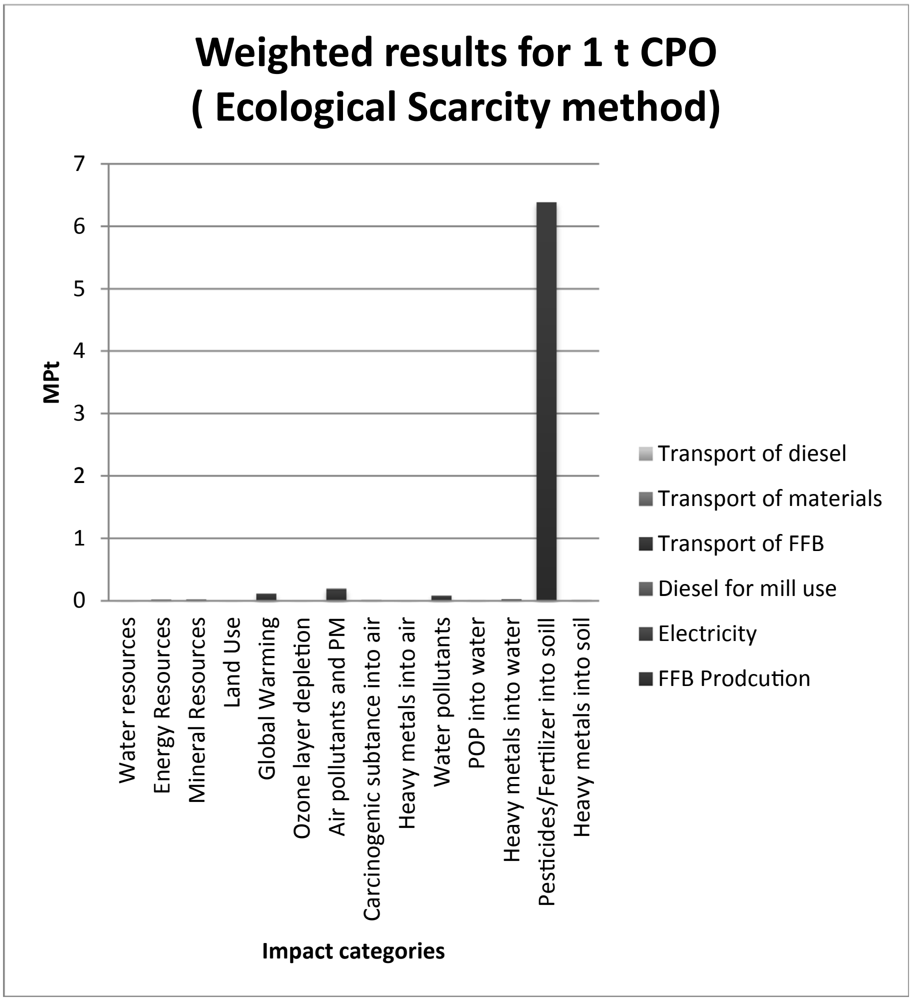

Fig. 8. Weighted LCIA for the production of 1 t CPO with Ecological Scarcity method.

5. Conclusions

The general perception in any agriculture based product would be the concerns about the water used directly by the crop which was one of the objectives for this study to gauge the impact of the water used by the oil palm trees. The results showed that the direct water use by the crops and process was minimal. This was because the oil palm plantations in Malaysia were firstly rain fed and not irrigated and secondly Malaysia is located in a water abundant region with very high availability of renewable water with a very low WSI. This shows the importance of the area chosen to plant oil palm and how this can affect the water footprint. As if the study was done for oil palm plantations at other zones with irrigation the findings will differ. The findings in this assessment showed that impacts were dominated by the indirect WF which is from upstream especially from the production and application of fertilisers and pesticides.

According to the ICCA LCA study, without chemical fertilisers and pesticides the agricultural yield would decrease from 85% to 30% depending on crop type, soil, technology, and climate (ICCA, 2009). This will in turn increase the amount of land converted to farming, which will increase the net amount of CO_2 emitted.

A balance has to be achieved to acquire good yields with enough fertiliser and pesticide application coupled with reduced impacts to the environment. It is recommended that oil palm plantations practice GAP. GAP addresses the management of the whole plantation system to obtain the best outcome both in yields and reduced economics and environmental burdens. GAP recommends:

5.1. Land management

The land is the most important factor as this is the source of the nutrients and water as well. For the oil palm trees land has to be carefully prepared to support the growth of new palms, when the old ones are felled for replanting after 25 years. During this stage, legume cover crops are planted to fix atmospheric nitrogen in the soil, to reduce soil erosion and improve water retention and retain the nutrients in the soil. This will improve soil properties, increase the soil's biological activity and suppress the growth of weeds (Tradewinds, 2017b).

5.2. Water management

Just like any crop oil palm trees needs a constant supply of water as unstable supply of water can create unnecessary stress to the trees and adversely affect their productivity (Sime Darby, 2017). Water management practices in oil palm plantations aim to maximise water efficiency, through various measures to balance operational requirements with the conservation of water resources. Measures must be taken to minimise the impact of droughts and

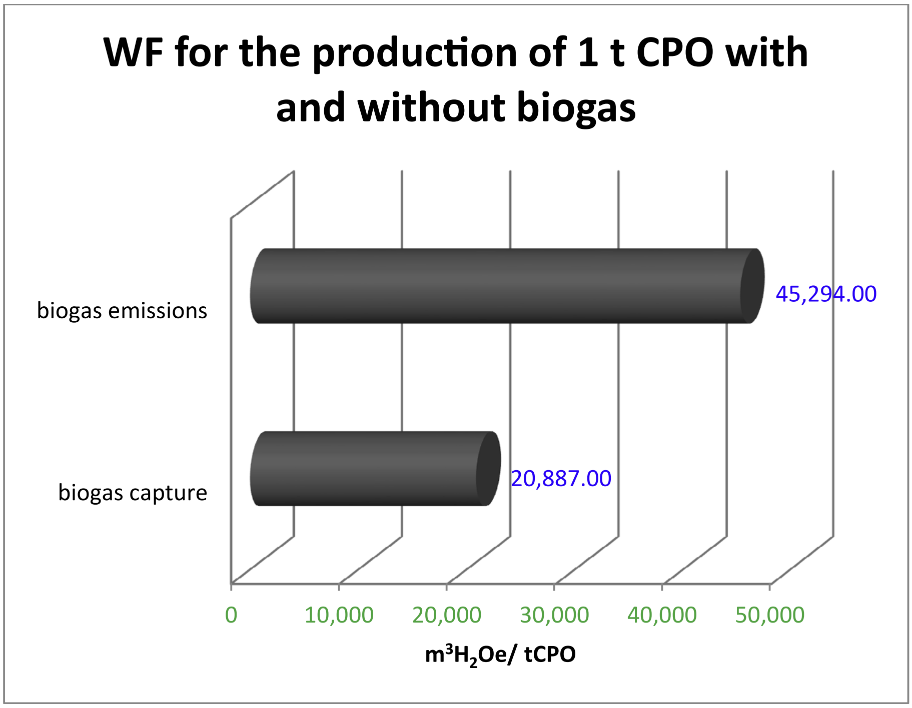

Fig. 9. WF for the production of 1 tonne CPO with and without biogas capture.

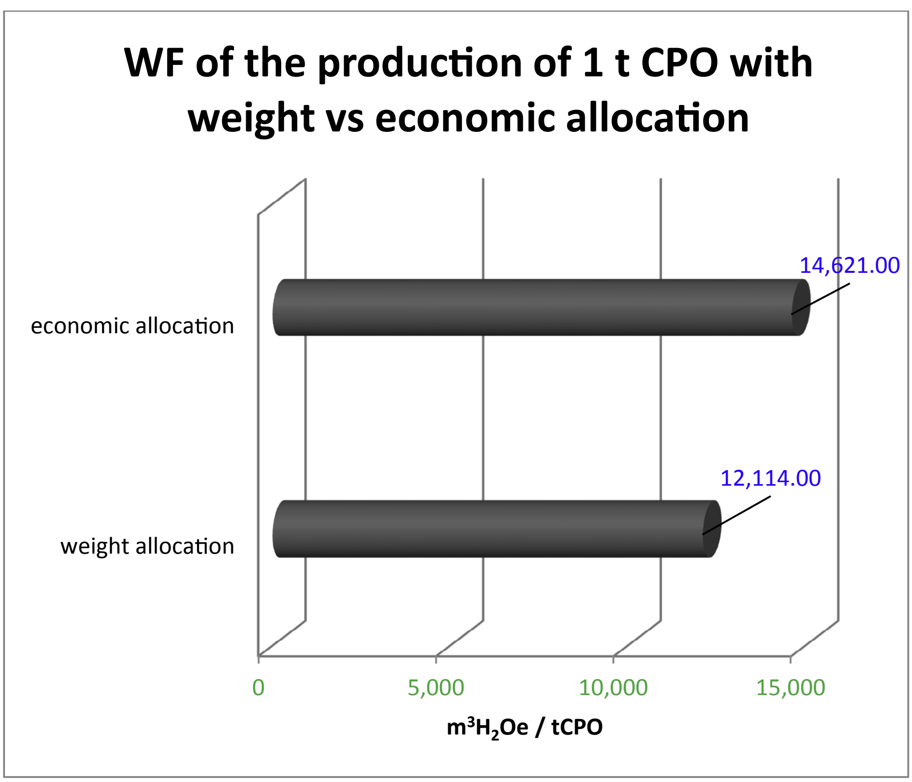

Fig. 10. Comparison of WF for the production of 1 t CPO with weight and economic allocation.

floods, optimise the use of rainwater and surface water, maximise utilisation of effluents from palm oil mills, and minimise the impact of saltwater incursions and acidity levels. (Tradewinds, 2017).

5.3. Fertiliser management

In most cases the soil nutrient availability is always lower than required for maintaining the optimum nutrient status. (Turner and

Gillbanks, 2003). Fertilisers are to be applied based on soil type and requirement by the crop. GAP recommends that in order to obtain the correct application rate of fertilisers, it should be based on the results of a complete fertiliser experiment (Turner and Gillbanks, 2003) as the fertiliser requirement for each location will differ depending on climate, soil conditions and standards of field maintenance. Precision fertiliser application has to be practiced in order to balance the fertiliser application as not to over or under fertilise. This will ultimately improve the environmental burden that is arising from the fertiliser.

5.4. IPM

The major sources of pest and disease in oil palm estates are leaf-eating caterpillars, rhinoceros beetles, Ganoderma basal stem rot, and rats. To manage their population, GAP recommends IPM which is the combined use of compatible methods of pests and diseases control that include ecological, physical, biological and chemical controls. IPM reduces use of chemical pesticides and negative environmental impacts (Piggott, 2002).

It is hoped that the findings of this study will help the oil palm industry better manage their water and consumption patterns by adopting good managerial practices like GAP. It is recommended that the magnitude of savings from the biogas capture be highlighted to enable more understanding for the oil palm industry to justify their huge investments to implement biogas capture facilities at their POMs and the choice of pathways and allocation procedures be made transparent with the results as outcomes may differ with the choice of a pathway and allocation as shown in this paper.

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